A Transient Tension Softening-Stiffening Model of Concrete

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Abstract:

During cracking process in reinforced concrete structures, the tensile stress transfer in concrete domain close to the tip of crack and low tensile strain field is always very small and is mainly governed by the fracture energy of cracked concrete. However, with propagation of cracks (large tensile strain), the tensile stress mobilized in cracked concrete is mainly governed by bond stress transferred from reinforcing bars. A generic tension stiffening-softening model is proposed to apparently take into account this effect in a unit model by considering the transition of tension stiffening model from plain concrete to reinforced concrete model.

Introduction:

The macroscopic stress transferring in cracked RC element in FEM is treated by average stress-strain relationship of concrete and reinforcing bars. The tensile stress transfer ability of concrete after cracking so called “ tension stiffening” is usually derived on long portion of RC tensile member, in which, many cracks are formed in the obviously smeared manner. However, this type of averaging cannot show the local deformation of RC element in the vicinity of each cracks, especially when the RC member has steep gradient of tensile stresses in the tensile portion. In this paper the deficiencies of existing tension stiffening models are pointed out and a new concept for tension stiffening is briefly described.

Modeling concept:

Fig. 1a shows typical test for development tension stiffening and also microscopic stress distribution for this specimen after progression of first crack in the specimen (before other cracks). Almost all deformation of specimen after cracking is localized in the vicinity of crack because close to the crack, the steel strain is so higher than other points along the reinforcing bar. The effect of length of averaging on the average tensile stress transferring due to the bond between concrete and reinforcement is shown in Fig 1b. For the same average stress, the average strain for longer length is smaller. With increasing the applied stress more cracks are developed in the RC member until it reaches to the stable crack pattern and finally yielding of reinforcement.

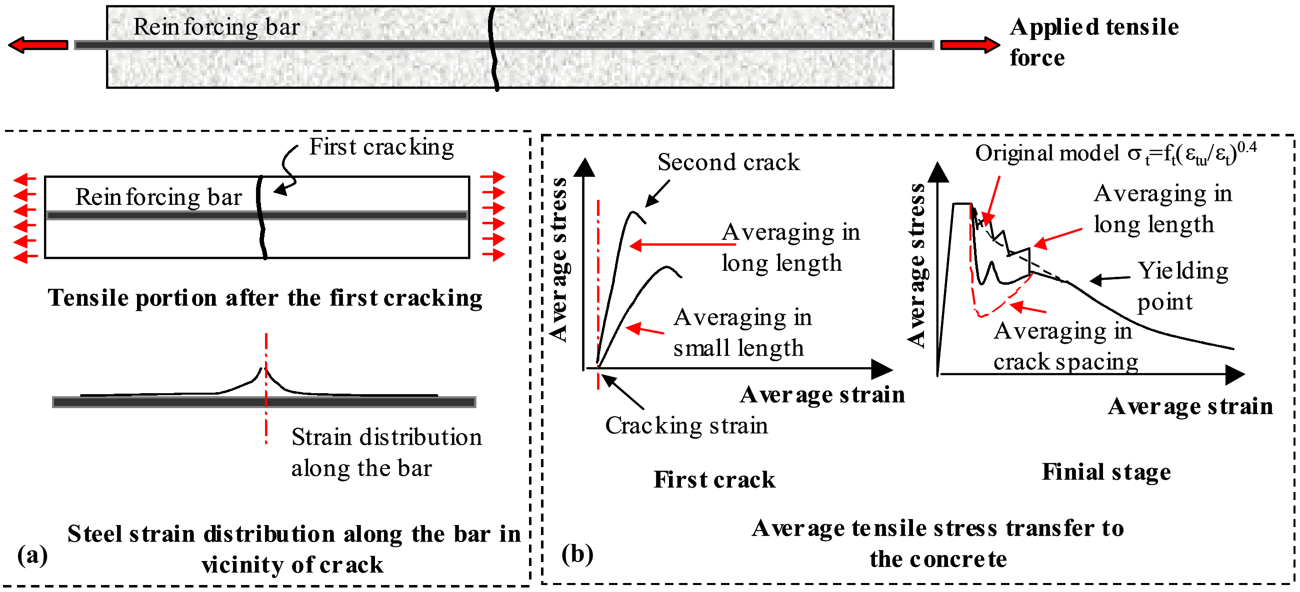

Fig. 1 Crack development in RC domain and effect of averaging length on tension stiffening.

Keywords: Tension stiffening, Crack, Shear, RC, FEM

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Fig. 1b schematically shows response of tensile member to the applied stress for different portion length of specimen. Lets look at the crack localization in FEM. If concerning element is under constant uniaxial stress and is long enough that many cracks form in the element, it is obvious to use the average stress-strain relationship derived based on the long length of tensile member. However in FEM, size of element is usually limited to small size (usually 20-50 cm), and also is not under constant stress field. Consider specimen shown in Fig 2, when the first crack localizes in the elements, the deformational behavior of this cracked part should coincide with the structural deformation. This means if the average stress-strain relationship of concrete is derived from longer length, the computed response is much stiffer than real response.

Transient tension softening-stiffening model:

The average stress-strain relationship of concrete after cracking can analytically derived through solving the governing equation and strain compatibility along the reinforcing bars. This method is utilized in this work, however the average stress-strain relationship of concrete is derived along the length of re-bar between two adjacent cracks (crack spacing). The crack spacing is considered for averaging, because the length of reinforcing bars, that through which the tensile stress transfers to the concrete, in the finial stage, is equal to the crack spacing. This has been shown that the tensile stress mobilized in cracked concrete due to bond is independent of reinforcement ratio. Tensile stress transfer to the concrete (σ_t) is summation of tensile stress due to bond (σ_b) and bridging stress transfer across cracks (σ_G) as:

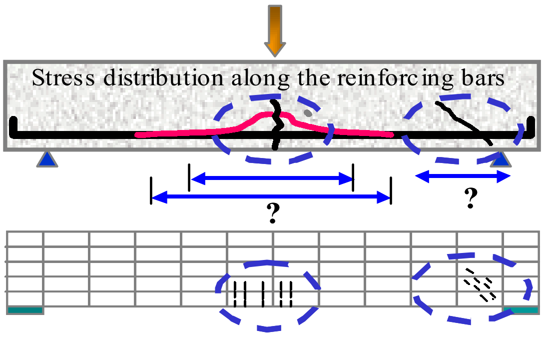

Fig. 2 Crack localization in FEM

$$\sigma_t = \sigma_G + \sigma_b$$

$$\sigma_G = f_t \left(\frac{\varepsilon_{tu}}{\varepsilon_t} \right)^{C_G}$$

$$\sigma_b = \left(\frac{1}{6} \right)^{0.4} f_t \left[5.5 \left(\frac{\varepsilon_t - \varepsilon_{tu}}{5\varepsilon_{tu}} \right) - 4.5 \left(\frac{\varepsilon_t - \varepsilon_{tu}}{5\varepsilon_{tu}} \right)^{1.25} \right] \quad ; \varepsilon_{tu} \le \varepsilon_t < 6\varepsilon_{tu}$$

$$\sigma_b = f_t \left(\frac{\varepsilon_{tu}}{\varepsilon_t} \right)^{0.4} \quad ; \varepsilon_t \ge 6\varepsilon_{tu}$$

where, f_t is tensile strength of concrete, ε_t and ε_{tu} are tensile strain of concrete and cracking strain, respectively. C_G is tension-softening parameter considered based on the fracture energy.

Verification of the model:

The model is utilized for nonlinear analysis of 3 RC beams: author's experiment, large critical shear beam[1] and bending case[2]. The comparison with experimental results shows the proposed model can better predict the structural response.

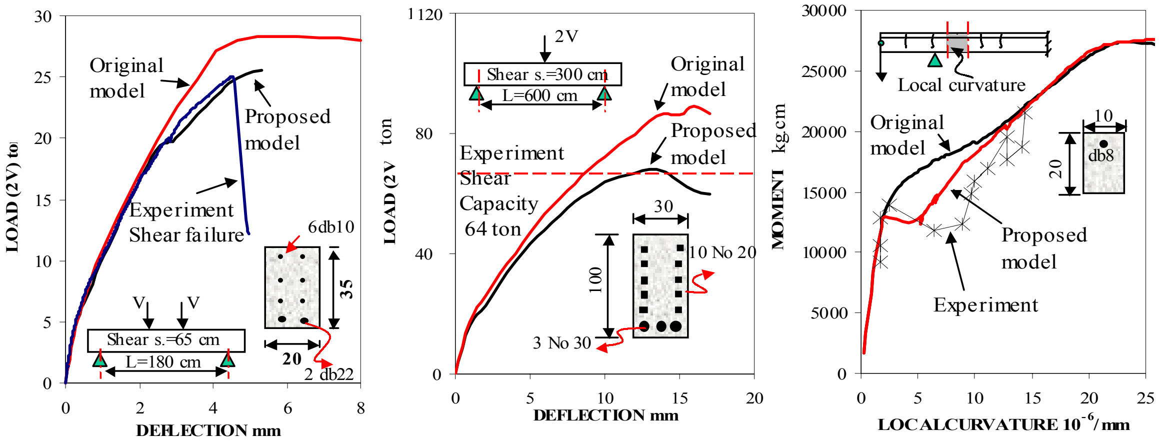

Fig. 3 Comparison with experimental results; (a) author's experiment,(b) large RC beam , (c) bending case.

References:

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